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NOTICES

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14. ABSTRACT

Moving human target sensing for airborne foliage-penetration (FOPEN) radar applications is considered. Target detection, parameter estimation, and image refocusing—along with clutter suppression—are obtained with a hybrid along-track interferometry (ATI)/displaced phase center antenna (DPCA) technique that exploits the responses from a multichannel sensing configuration. The processing algorithm is evaluated using the scattering returns from large-scale, full-wave electromagnetic simulations of a scene consisting of a walking human embedded in a forest stand. Within the prescribed simulation framework, analysis is also performed to examine the effects of the trees and the human gait movement on target localization and image quality.

15. SUBJECT TERMS

electromagnetic scattering, tree scattering, foliage penetration radar, target localization, interferometry

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1. Introduction

Understandably, as forests cover approximately 30% of the globe's land surface, the detection of moving targets concealed in forest environments is a problem of continued interest, especially as pertinent to airborne military surveillance applications. Although various clutter-suppression techniques have been developed in the general area of ground moving target indication (GMTI), including change detection,[1] along-track interferometry (ATI),[2] displaced phase center antenna (DPCA),[3,4] and space-time adaptive processing, the focus of most existing works has been on the detection of surface vehicles (from either spaceborne or airborne platforms). The detection of moving humans hidden under tree cover—which poses a greater challenge due to the need to discriminate responses that have both very weak intensities and very small Doppler components—has been addressed in far fewer studies. For example, the sensing of human targets in foliage has been considered by Sjögren et al.[5]—wherein the signatures of the walking human in single-pass, single-channel synthetic aperture radar (SAR) images are examined, and by Jao et al.[6]—wherein adaptive array processing is applied to detect dismounts. Given that there has been an increased impetus in attaining SAR imaging and GMTI simultaneously, a hybrid ATI/DPCA method is exploited for moving human target detection in this work. The technique assumes the availability of single-pass data from a multichannel foliage-penetration (FOPEN) radar, and enables target velocity parameter estimation and, subsequently, target refocusing in the SAR imaging domain. Verification of the processing algorithm is obtained with scattering data from a numerical solver that fully characterizes the electromagnetic responses of a scene containing realistic tree structures and a walking human.

2. Hybrid ATI/DPCA Method

With the sensing scenario of consideration as depicted in Fig. 1, an airborne platform of the following configuration is assumed: the radar has 2 transmitters and 3 receivers; the receiver array—with interelement separation distance d—is linearly arranged in the along-track (or azimuth) direction; furthermore, the 2 transmitters are colocated with the first 2 receivers. Over coherent processing time T, the platform is assumed to be flying with velocity v_p along a linear flight path, and the sensing geometry is akin to that of the stripmap mode; and the human target, located at reference position (x_t, y_t) at the midpoint of the coherent processing time, is walking with constant velocity vector (v_x, v_y) along a straight line. The scattering data collection proceeds as follows: at each azimuth sampling time t_k, the scene is illuminated by Transmitter 1, and the scattered fields are captured at Receivers 1 and 2; then at azimuth sampling time $t_k + d/v_p$, the scene is illuminated by

Transmitter 2 and the scattered fields are captured at Receivers 2 and 3. In essence, 4 sets of scattered fields are generated, viz., c_{11}, c_{21}, c_{22}, and c_{32}, where in each case, the first subscript index denotes the receiver number and the second denotes the transmitter number. For DPCA processing, the operation $c_{11} - c_{22}$ is performed, the result of which can be estimated as a linear FM signal. The parameters of this linear FM signal—which are defined by the unknown target velocity and reference position vectors—are determined using a fractional Fourier transform procedure.[7] The target reference position vector itself is deduced with the phase of the output from a clutter-suppressed ATI operation of the form $(c_{11} - c_{22})(c_{21} - c_{32})^*$. Once the linear FM parameters and reference position vector are found, the target velocity vector (v_x, v_y) can be calculated. Subsequently, having estimated the target parameters, phase compensation on the clutter-suppressed signal $c_{11} - c_{22}$ can be carried out to de-blur the target response—as well as to relocate it to its correct position—in the imaging domain.

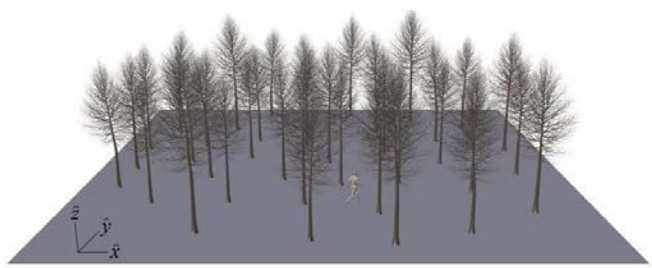

Fig. 1 Human target walking through a forest stand with 36 randomly generated trees

3. Numerical Experiments with Full-Wave Simulation Data

The scattering responses of the scene in Fig. 1 are obtained with the full-wave solver presented by Liao and Dogaru[8,9]; specifically, the large-scale simulation framework employs a parallelized finite-difference time-domain algorithm for deriving the far-field responses of the scene over the 300–400 MHz band. The forest stand is composed of 36 randomly generated trees situated directly over a flat, finitely conducting ground. A human target is assumed to be moving across the scene, with poses for its walk cycle synthesized from motion-capture data.[10] Essentially, frame-by-frame simulation of the scene is performed over the coherent processing time to capture the effects of both the displacement and the gait movement of the target. The overall dimensions of the computational domain are approximately 29 m × 29 m × 9 m. The trees, ground, and human model are assumed to be dielectrically homogeneous with relative dielectric constant and conductivity $(\varepsilon_r, \sigma_d)$ of (13.9, 39 mS/m), (5.45, 20 mS/m), and (48.8, 662 mS/m), respectively.

The hh-polarized imaging results from the hybrid ATI/DPCA method discussed in the previous section are displayed in Fig. 2. For this sensing scenario, $v_p = 100$ m/s, $(v_x, v_y) = (1.0$ m/s, 0.75 m/s$)$, and $T = 16.9$ s; the along-track direction is taken to be parallel to the x-axis; the radar is pointed toward $\hat{y}$ with a depression angle of 15°; and the average slant range to the target is approximately 5.8 km.

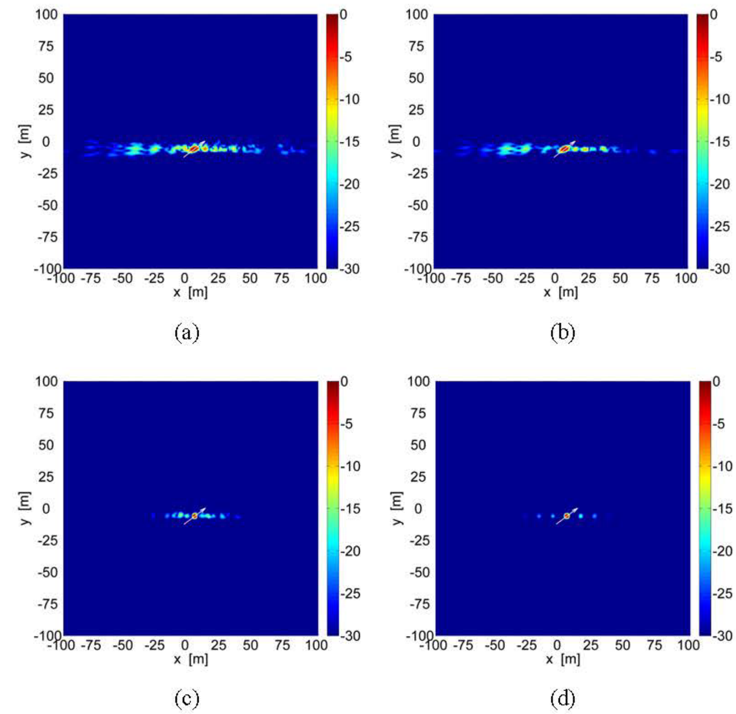

Fig. 2 GMTI-SAR images (*hh*-polarized) from hybrid ATI/DPCA method for scene in Fig. 1: a) with trees, moving human with variable pose (as constructed from motion-capture walk cycle); b) without trees, moving human with variable pose (as constructed from motion-capture walk cycle); c) with trees, moving human with constant pose; and d) without trees, moving human with constant pose

It is seen from Fig. 2a that the target is detected and localized (the path of the target is indicated with the white arrow in the images); however, there is also a significant amount of imaging artifact spreading in the cross-range direction. The main cause of this smearing does not stem from the presence of the trees: as evident from Fig. 2b, for the same sensing setup, similar defocusing appears in the image for the scene without the trees and with only the walking human. It is surmised that the manifestation of the artifact arises from the fact that the processing algorithm here presupposes a simple target moving with a single velocity vector, whereas in actuality, the walking human is a fluctuating complex target, with many body components moving with different velocity vectors. To verify this conjecture, the simulation scenario is reconsidered using a human target with a constant pose—

that is, from one frame to the next, the target is simply displaced along its walking path, without its gait movement. The results in Figs. 2c and 2d confirm the moving target, whether it is in the open or in the trees, can be well focused without the smearing effect if the movements of individual body parts are excluded. At least in this example and for the hh response, although the multiscattering interactions of the trees and the target do introduce some additional image degradation, those effects seem to play a less significant role than the fluctuating nature of the composite target.

For comparison purposes—and for the sake of completeness—imaging results derived from conventional DPCA and ATI techniques are also included here, in Figs. 3 and 4. It is evident that the target is detected in all cases, and the clutter response is suppressed—when the simulated scene does contain the trees. In general, for a target in motion, its DPCA or ATI imaging response is displaced from the actual target location; in these examples, this offset distance along the cross-range direction is estimated as

$$x_{offset} = -R_o \frac{v_y}{v_p}$$

where R_o is the broadside slant range of the target. Of course, the theoretical result, previously mentioned, does not include the effects of the gait movement. Other than spreading the response in the cross-range direction, the gait movement can also introduce an additional radial velocity component that can cause the main image of the target to be displaced by an additional amount. This can be readily observed, for instance, by comparing Figs. 3b and 3d.

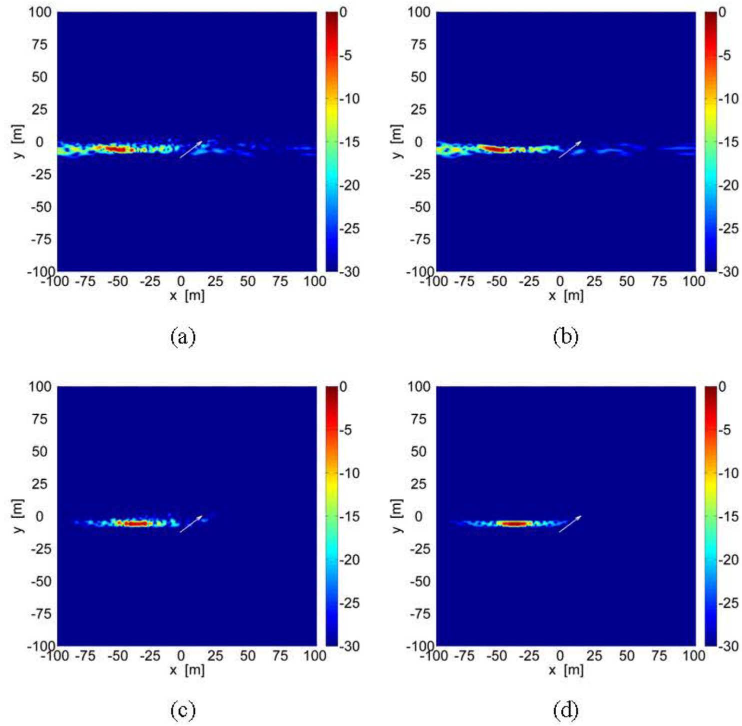

Fig. 3 GMTI-SAR images (*hh*-polarized) from conventional DPCA method for scene in Fig. 1: a) with trees, moving human with variable pose (as constructed from motion-capture walk cycle); b) without trees, moving human with variable pose (as constructed from motion-capture walk cycle); c) with trees, moving human with constant pose; and d) without trees, moving human with constant pose

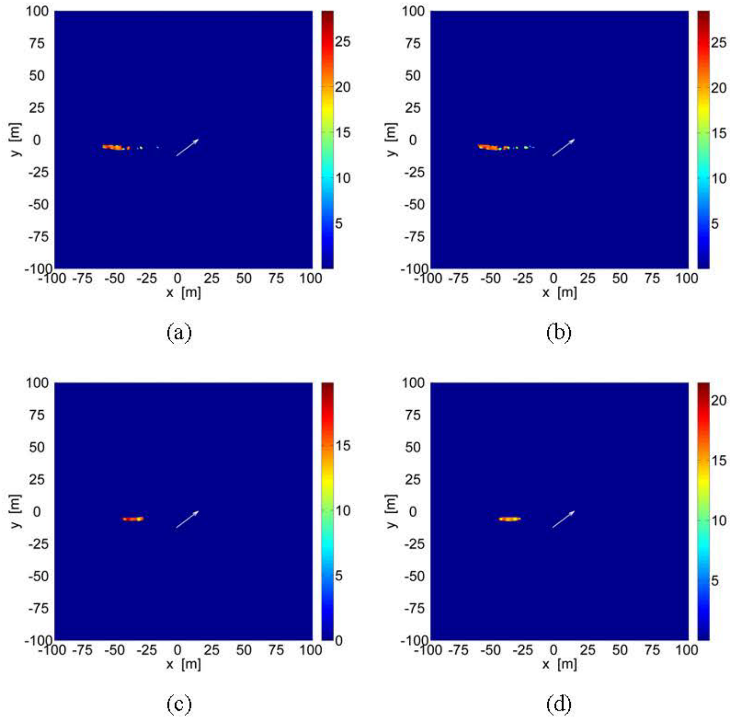

Fig. 4 GMTI-SAR images (*hh*-polarized) from conventional ATI for scene in Fig. 1: a) with trees, moving human with variable pose (as constructed from motion-capture walk cycle); b) without trees, moving human with variable pose as constructed from motion-capture walk cycle); c) with trees, moving human with constant pose; and d) without trees, moving human with constant pose

4. Conclusions

A hybrid ATI/DPCA method is investigated for moving human target detection, parameter estimation, and localization, as relevant to airborne FOPEN sensing. The processing algorithm is demonstrated with scattering data from an electromagnetic solver that fully characterizes the responses of a scene consisting of a moving human target in a forest stand. Numerical experiments indicate that the gait movement of the target can lead to image defocusing and has to be included in order to completely understand the imaging response.

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List of Symbols, Abbreviations, and Acronyms

ATI	along-track interferometry
DPCA	displaced phase center antenna
FM	frequency modulation
FOPEN	foliage-penetration (radar)
GMTI	ground moving target indication
SAR	synthetic aperture radar

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